LONDON-WEST MIDLANDS ENVIRONMENTAL STATEMENT

Volume 5 | Technical Appendices

CFA21 | Drayton Bassett, Hints and Weeford

Drayton Bassett, Hints and Weeford river modelling report (WR-004-014)

Water resources

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High Speed Two (HS2) Limited,
Eland House,
Bressenden Place,
London SW1E 5DU

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Appendix WR-004-014

Environmental topic:	Water resources and flood risk assessment	WR
Appendix name:	Modelling	004
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1 Overarching modelling approach

1.1 Introduction

1.1.1 The Country North section of the Proposed Scheme crosses numerous watercourses with the potential for affecting flood risk. Hydraulic modelling has been carried out to assess the current (baseline) river flood risks at each of these watercourse crossings and the potential impacts of the proposed culvert and viaduct structures. Therefore, the primary objective of this assessment was to assess the impact of the Proposed Scheme on river flood risk.

1.1.2 The outcome of this assessment has aided the design team to determine the type and dimension of structures required to convey the watercourse flows; and mitigation measures for any remaining residual flood risk.

1.1.3 A hydraulic modelling assessment of flood risk was undertaken for watercourses affected by the Country North section. These watercourses were grouped into seven CFA in the Country North section. Existing hydraulic models of the watercourses have been utilised where available and new river hydraulic models were built for the other watercourses. This report describes the hydraulic modelling processes and outcomes of this assessment.

1.1.4 The main conclusions from this modelling form the basis of the river flood risk in the Flood Risk Assessment for CFA21 (Volume 5: WR-003-021). These conclusions are also reported within the Water Resources and Flood Risk Assessment section of Volume 2 of the Environmental Statement (ES).

1.2 Hydrology

1.2.1 Watercourses with existing hydraulic models adopted standard Flood Estimation Handbook (FEH) techniques for hydrological assessment. The hydrology of these models was reviewed for suitability for use in this study.

1.2.2 For the watercourses with no existing hydraulic models, hydrological assessments were undertaken in this study to determine the design flows.

1.2.3 The hydrological catchments of the watercourses to each of the route crossings have been determined from the FEH CD-ROM[1] for watercourses represented in this data set. For the purposes of this assessment it was assumed that catchment boundaries as represented in the FEH CD-ROM were correct, therefore a detailed assessment of catchment boundaries has not been completed. The catchment descriptors have also been taken from the FEH CD-ROM and updated for urban expansion to 2012, using Equation 6.8 in Volume 5 of the FEH[2]. This is a standard industry technique.

1.2.4 River flows at watercourse crossing locations were determined using the Revitalised Flood Hydrograph (ReFH) method[3] in the first instance. In line with the current Environment Agency flood estimation guidance, the ReFH method is deemed acceptable for the majority of catchments along the route and is the most time

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[1] Centre for Ecology and Hydrology (2009) *FEH CD-ROM Version 3*, ©NERC (CEH).
[2] *Flood Estimation Handbook – Volume 5: Catchment Descriptors (1999)*, Centre for Ecology & Hydrology (CEH).
[3] *The revitalised FSR/FEH rainfall-runoff method: Supplementary Report No. 1 (2007)*, Centre for Ecology & Hydrology (CEH).

efficient method for determining flows for studies where numerous flows are required.

1.2.5 The ReFH method is not considered acceptable for all catchments, in this case those classed as highly permeable. Based on the FEH CD-ROM catchment descriptors, a number of the catchments are classed as highly permeable and hence in line with current Environment Agency guidelines[4], an alternative method was required. Therefore, at these locations, the FEH Statistical method, with a permeable adjustment was utilised, as recommended in the guidelines.

1.2.6 Not all watercourses that will be crossed by the route were represented in the FEH CD-ROM; therefore, the catchment boundaries could not be determined using the FEH CD-ROM. In these instances, catchment boundaries have been determined through the use of topographic data from Light Detection and Ranging (LiDAR) data and Ordnance Survey (OS) mapping at a 1:10,000 scale. At locations of uncertainty, a slightly larger catchment has been assumed as a conservative approach. Flows for these catchments were determined through a conservative area scaling method. Based on the flows estimated for FEH CD-ROM represented catchments, a maximum flow rate of 1.4 and 2.6m^3/s per km^2 was calculated for the 1 in 100 (1%) annual probability and 1 in 1000 (0.1%) annual probability events respectively. These flows rates, along with a 10% error allowance (to prevent an underestimation of flow), were used as scaling factors.

1.2.7 The estimated peak flows were used as either a constant inflow boundary or as a full hydrograph. The peak flows estimated using this method were for the 1 in 5 (20%) annual probability, 1 in 100 (1%) annual probability and 1 in 1000 (0.1%) annual probability events. Flow during the 1 in 100 (1%) annual probability event with an allowance for climate change was estimated by factoring the 1 in 100 (1%) annual probability flow by 20% (refer to 'Section 3 – Design Criteria' of the Flood Risk Assessment WR-003-021).

1.3 Hydraulics

General approach

1.3.1 The hydraulic modelling approach depended on the characteristics of the particular watercourse and floodplain hydraulics. The approach of either steady or unsteady modelling was based on whether there were rapid increases or decreases in flows, flood storage areas or structure impacts on channel/floodplain flows. The modelling approach also varied based on requirements of assessing the flow routes either in one dimension or two-dimension.

1.3.2 The modelling approach adopted in this study was as follows:

- if the modelling was utilised for sizing the culvert crossings on watercourses with no significant floodplain attenuation or structure impacts, steady state one dimensional modelling was adopted;
- if there was significant floodplain attenuation and/or structure impacts on channel/floodplain flows, one dimensional hydrodynamic modelling was

[4] Environment Agency (2012) *Flood estimation guidelines (197_08)*.

adopted; and

- if there was significant floodplain attenuation and/or structure impacts on channel/floodplain flows, and a requirement for accurately defining the flood extents, two dimensional or a one dimensional two dimensional combination modelling was adopted.

1.3.3 Existing models were first reviewed to assess their suitability for use. If more recent data such as topography was available the models were updated accordingly. If the level of detail within the model, such as the floodplain, was not appropriate, the model was upgraded accordingly.

1.3.4 The hydraulic modelling approach was based on the Environment Agency guidelines[5].

1.3.5 Two industry standard modelling packages have been utilised as part of this assessment: ISIS (version 3.6) and TUFLOW (version 2012).

Hierarchical approach

1.3.6 Any existing Environment Agency models for the watercourses were used to assess the current and future flood risk impacts of any watercourses crossing the route.

1.3.7 For watercourses without existing hydraulic models, the modelling process was carried out in a phased manner to assess the baseline flood risk and impacts of the Proposed Scheme. In the first phase, the watercourses with culverted crossings were modelled as simple unsteady one dimensional hydraulic models, to assess the adequacy of culverts in conveying flood flows. In the second phase, watercourses for both culverted and viaduct crossings were modelled as two dimensional hydrodynamic models to define the flood extents and assess the impacts of the various structures on flood risk. The two dimensional model outputs were then used to inform the design team of flood risk.

1.3.8 All the models were run for the 1 in 100 (1%) annual probability with an allowance for climate change and 1 in 1000 (0.1%) annual probability events. Some of the models were run for the 1 in 20 (5%) annual probability where the potential impacts on flood risk could affect vulnerable receptors.

1.3.9 The 1 in 100 (1%) annual probability with an allowance for climate change peak water levels for the baseline and Proposed Scheme were compared upstream and downstream of the crossing to assess the impact on flood risk. The scheme impact on flood risk and the width of the 1 in 100 (1%) annual probability with an allowance for climate change flood extents, defined the type of structure to be used at the crossings i.e. culvert or viaduct and the dimensions of culverts/viaducts. The structure type was selected based on its adequacy in conveying flood flows without significantly affecting flood risk.

1.3.10 The peak water levels for the 1 in 1000 (0.1%) annual probability event confirmed whether the vertical alignment met the design criteria (refer to 'Section 3 – Design Criteria' of the Flood Risk Assessment WR-003-021).

[5] *'Requirements for completing computer river modelling for flood risk assessments – Guidance for developers' Version 3.0 (August 2009)*, Environment Agency.

Input data

1.3.11 The topographic data used was LiDAR data that was flown in 2012, covering the extent of the Proposed Scheme, providing data as fine as up to 0.2m horizontal resolution. This data was used to create digital terrain models (DTM) for use within the hydraulic models. In most cases, the DTM has been resized to a 1m resolution for suitability in the two dimensional models. For watercourses without existing hydraulic models, there were no topographic surveys available and hence river sections and floodplain topography were derived from these DTM.

1.3.12 For existing models, the floodplain topography was updated with this new DTM. The channel topography in these models was taken from topographic surveys undertaken previously.

1.3.13 Inflows to the watercourses were taken from the hydrological assessments as discussed in Section 1.2 of this report.

1.3.14 The data for the Proposed Scheme model scenario was taken from the scheme drawings.

One dimension modelling

1.3.15 In the first phase, one dimensional ISIS models were constructed representing a 200m to 300m reach of the watercourse. The purpose of these models was to assess the adequacy of culverted crossings in conveying flows. These models used the LiDAR data to define extended cross sections which included the channel and floodplain topography. The roughness of the channels and floodplains is defined by the Manning’s roughness parameter. The Manning's values were based on the particular land use type as observed from aerial photographs. Steady state flows were applied as upstream inflow boundaries and a normal depth boundary was applied at the downstream extent. The normal depth boundary was based on the bed slope of the topography at that location and is considered suitable for the purpose of the modelling.

1.3.16 The Proposed Scheme model included rectangular conduit units to represent the structures at the crossings. There were two types of culverts adopted: a minimum culvert size of 2m by 1.5m and a maximum culvert size of 4m by 2m. The dimensions adopted here represent the flow area of the culvert rather than the full dimensions of the culvert that would need to be larger to accommodate depressed inverts and mammal ledges as appropriate. The lengths of the culvert were based on the width of the route crossings as defined in the post consultation route.

Two dimension modelling

1.3.17 In the second phase, unsteady state two dimensional TUFLOW models were built to accurately define the flood extents and floodplain attenuation. The two dimensional models were built on a 5m cell resolution with LiDAR data used to create the DTM, which defined the floodplain and channel topography.

1.3.18 It should be noted that components within a two dimensional TUFLOW model such as 'SXZ', 'HX', Z-polygon, Z-Shape polygons, etc., are based on naming conventions as defined in the TUFLOW manual[6].

1.3.19 The Manning's roughness values of the channels and floodplains were based on the particular land use type as observed from aerial photographs.

1.3.20 The inflow to each watercourse was applied upstream using a TUFLOW boundary condition (BC) polyline layer, linking it to a flow time series within a boundary condition database. The flow type is either constant flow or hydrograph flow, depending on the attenuation within the floodplain. A flow-head (HQ) polyline layer was used for the downstream boundary, based on the slope of the floodplain at that location; which was considered suitable for the scale and level of detail of the modelling. The models have been run at a two second timestep for varying durations.

1.3.21 The Proposed Scheme model was built by adding either culvert or viaduct structures to the baseline model at the watercourse crossings.

1.3.22 Viaduct structures have been modelled by adding the Proposed Scheme embankments as Z-polygon or Z-Shape polygon layers with an opening at the viaduct crossing. The Z-polygon or Z-Shape polygon layers are Geographic Information System (GIS) polygons with elevations. Where piers were modelled, they were represented as Flow Constriction (FC) shape layers. The soffit levels were not added into the model. This was because the 1 in 1000 (0.1%) annual probability modelled peak flood levels, along with sufficient clearance, will form the basis of designing the soffit heights (refer to Section 3, Design Criteria, of the Flood Risk Assessment WR-003-021).

1.3.23 Culvert structures have been modelled by adding a one dimensional network layer representing the extent of the culvert, the length of which was determined by the width of the route at the crossing point (including embankment earthworks and any landscaping). Inverts were defined at the inflow and outflow points of the culvert extracted from the LiDAR DTM for the area. This one dimensional network layer was connected to the two dimensional domain with a 'SXZ' point link; a GIS point used in the modelling software for one dimension two dimension linking. An embankment was modelled across the route as a Z-polygon layer, covering the extent of the upstream floodplain at the route crossing so that all flow was routed through the culvert.

One dimension-two dimension linked modelling

1.3.24 In certain cases where existing one dimensional models were not representing complex channel-floodplain interactions accurately, dynamically linked one dimensional-two dimensional models were constructed. The channel component was represented in one dimension and the floodplain component in two dimensions. One dimensional-two dimensional models were built using ISIS-TUFLOW.

[6] TUFLOW User Manual, 2010, BMT WBM

1.3.25 The flows between the one dimensional and two dimensional model components were controlled via a GIS polyline layer ('HX' layer), the spill levels of which are defined by the channel bank levels or DTM levels.

1.3.26 In the Proposed Scheme scenarios, the viaduct structures are represented as discussed earlier in the two dimensional modelling section (Section 1.3.22 of this report).

Sensitivity assessments

1.3.27 Sensitivity assessments have been undertaken on various parameters of the models to reflect the uncertainties and impacts on modelled flood levels. Assessments have been carried out on inflows and culvert blockages. In the case of viaduct crossings, sensitivity was undertaken on inflows.

1.3.28 Sensitivity on inflows was carried out by varying the 1 in 100 (1%) annual probability with an allowance for climate change and the 1 in 1000 (0.1%) annual probability flows by 20%. This was undertaken for the baseline and post scheme scenarios, unless stated otherwise.

1.3.29 Sensitivity has also been carried out on Proposed Scheme scenarios with culvert structures by adding 10% blockage. Resulting models have been run for the 1 in 100 (1%) annual probability with an allowance for climate change and the 1 in 1000 (0.1%) annual probability events.

1.4 Assumptions and limitations

Hydrology

1.4.1 The catchment boundaries and catchment descriptors as taken from the FEH CD-ROM are correct and accurately represent the catchments in reality.

1.4.2 For catchments not classed as highly permeable, the ReFH method results in the most accurate estimation of flow at the location of the crossings in comparison to other methods.

1.4.3 The FEH Statistical method with permeable adjustment results in the most accurate estimation of flow at catchments classed as highly permeable.

1.4.4 The flow scaling method, which is based on area, results in conservative flow estimates for catchments which are not represented in the FEH CD-ROM (refer to Section 1.2 of this report for detail).

1.4.5 There are no external influences on flow at the location of the crossing, such as significant abstractions or discharges.

1.4.6 A 20% allowance for climate change on peak flow rates has been used for the assessment of river flood risk.

Hydraulic modelling

1.4.7 Only river flood risk was considered during the hydraulic modelling in this assessment.

1.4.8 For watercourses without existing hydraulic models, the watercourse geometry was extracted from the LiDAR DTM with the channel width defined by the 5m cell

resolution of the two dimensional model. Therefore, the watercourse geometry is not well defined, the consequence of which is an underestimate of the channel conveyance and hence, an overestimation of the floodplain inundation.

1.4.9 There were certain watercourses with road crossing structures upstream or downstream of a route crossing, causing a significant impact on hydraulics. OS Mapping and aerial photography were used to assess the location of the structures. The inverts of any culvert structure were assumed to be the channel bed levels from the LiDAR DTM; and structure widths as the width of the channel.

1.4.10 In the Proposed Scheme for models involving viaducts, the structure was represented by the piers and embankments. The scheme drawings were used to obtain the footprint of the piers and the dimensions incorporated into the model. The soffits of the viaducts were not modelled as the design approach for the structures is to include a suitable clearance between peak flood level and the structure soffit.

2 Modelling at watercourse crossings

2.1 Overview

2.1.1 River modelling undertaken at the various watercourse crossings for CFA21 is summarised in Table 1, along with the modelling methodologies adopted. Figure 1 (below) identifies the location of each of these structures.

Table 1: River models at watercourse crossings

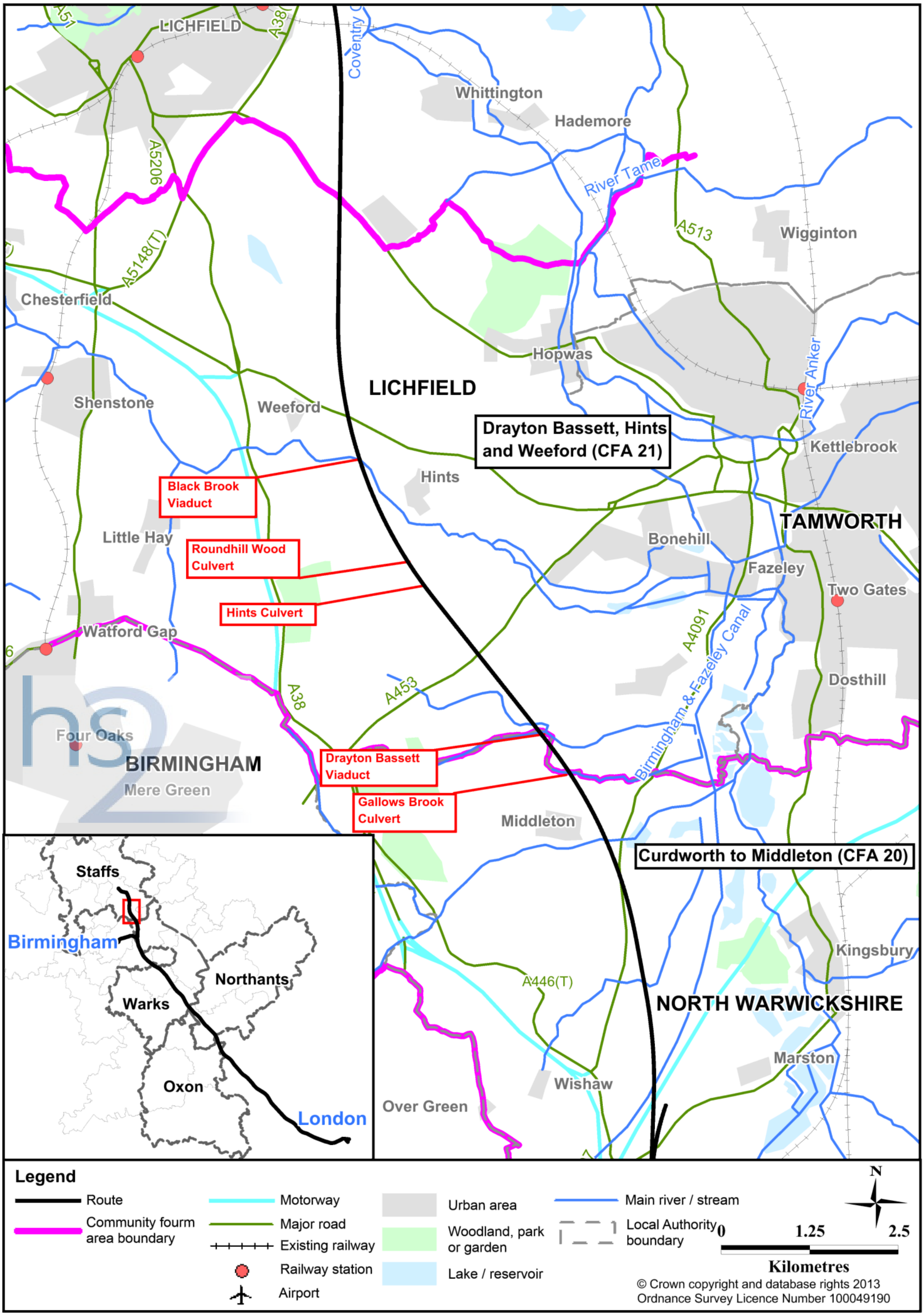
Crossing name	Watercourse identifier	Watercourse	Hydrology	Hydraulic modelling
Gallows Brook culvert	SWC-CFA21-001 (map WR-01-035, H5)	Ordinary watercourse (Gallows Brook)	ReFH	two dimensional hydrodynamic
Drayton Bassett viaduct	SWC-CFA21-002 (map WR-01-035, G5)	Ordinary watercourse (tributary of the River Tame)	ReFH	two dimensional hydrodynamic
	SWC-CFA21-003 (map WR-01-035, G5)	Ordinary watercourse (tributary of the River Tame)		
Hints culvert	SWC-CFA21-006 (map WR-01-035, D6)	Ordinary watercourse (tributary of Bourne Brook)	ReFH	two dimensional hydrodynamic
Black Brook viaduct	SWC-CFA21-009 (map WR-01-035, B5)	Main river (Black Brook)	ReFH	two dimensional hydrodynamic

2.1.2 A summary of the modelling for the two culvert structures (Gallows Brook culvert No1 and Hints culvert) is described in Section 2.2 of this report. The modelling is described in detail for each of the viaduct structures in the subsequent sections of this report.

2.1.3 It should be noted that the watercourse SWC-CFA21-008 at the location of Roundhill Wood culvert has not been modelled. This was because the watercourse was already culverted under the route. There was a hydrological assessment undertaken to estimate the design flow through the watercourse as described in Section 3 of this report. These flow estimates showed that a minimum culvert size of 2m x 1.5m through the Proposed Scheme embankments would be adequate to convey flows.

2.1.4 The details of the specific modelling methodologies, hydraulic constraints and any assumptions of each of the watercourse crossings are discussed in the following sections.

Figure 1: Location plan



2.2 Culverts

2.2.1 Two dimensional TUFLOW hydraulic models were built for the watercourses at location of the Gallows Brook culvert and Hints culvert. The modelling used the general methodologies for two dimensional modelling as discussed in Section 1.3 of this report. The structures adopted at the various culvert crossings along with their impacts on peak flood levels are summarised in Table 2. The structure dimensions of width (W), height (H) and length (L) in metres is also provided in this table.

2.2.2 The methodology applied for the hydrological assessment is provided in the FEH proforma in Section 2.4.14 of this report.

Table 2: Modelled peak levels at culvert crossings

Watercourse identifier	Structure dimensions (WxHxL)	Flood event	Peak Flood Level		Δ flood level (mm)	Length of Impact Upstream Reach[7]
			Baseline	Scheme		
SWC-CFA21-001	2m x 1.5m x 43m	1 in 20 (5%)	78.791mAOD	78.791mAOD	0	<20m
		1 in 100 (1%) climate change	78.796mAOD	78.796mAOD	0	
		1 in 1000 (0.1%)	78.819mAOD	78.807mAOD	-12	
SWC-CFA21-006	2m x 1.5m x 205m	1 in 100 (1%) climate change	91.732mAOD	91.732mAOD	0	<50m
		1 in 1000 (0.1%)	91.752mAOD	91.751mAOD	-1	

2.2.3 For the Gallows Brook culvert structure there is no increase in peak levels for the 1 in 100 (1%) annual probability with an allowance for climate change event. Increases in peak levels for this event of greater than 10mm were limited to a reach of 20m upstream of the crossing. Therefore, the culvert structure does not significantly increase flood risk and has adequate capacity to convey flood flows.

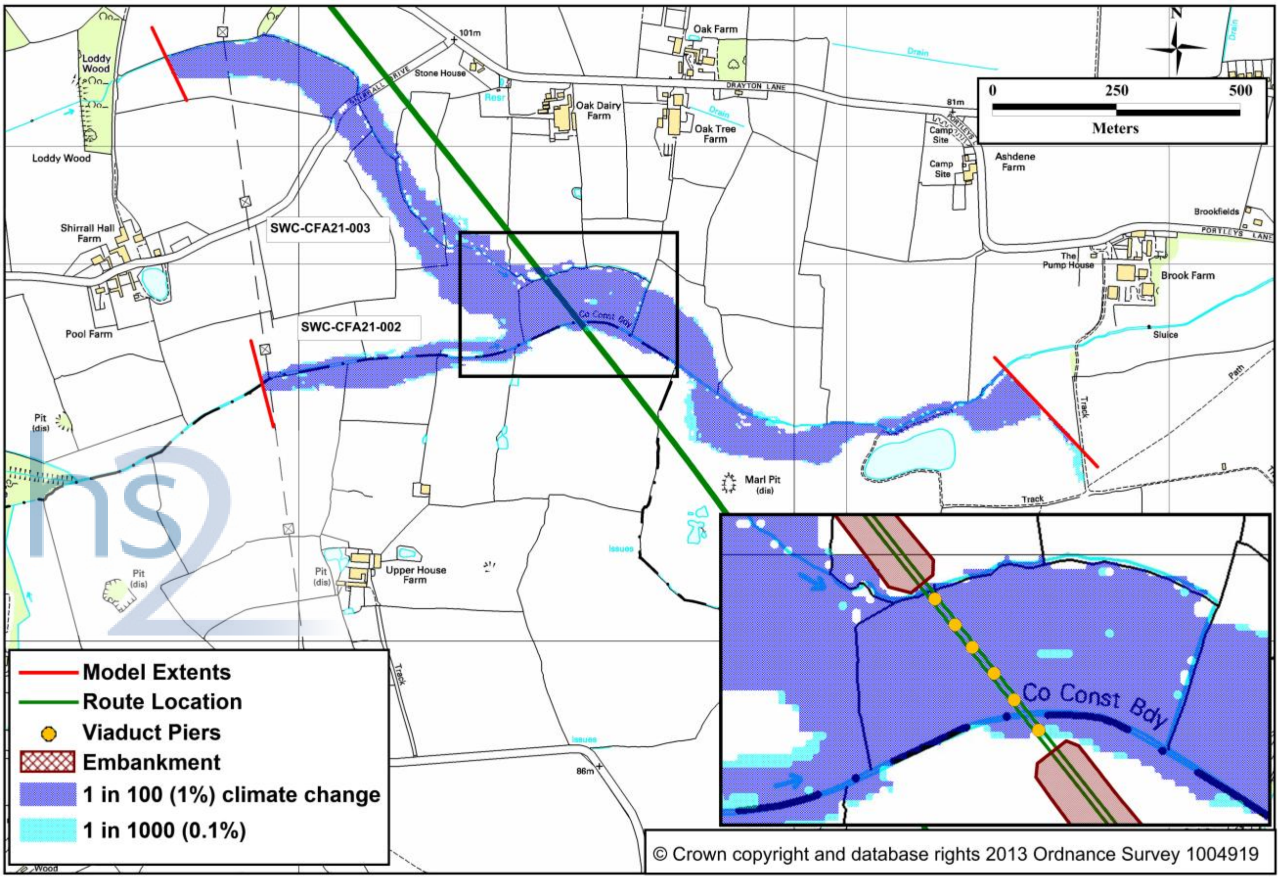
2.2.4 For the Hints culvert there were no increases in peak levels for the 1 in 100 (1%) annual probability with an allowance for climate change event. Increases in peak levels for this event greater than 10mm were limited to within 50m upstream of the watercourse crossing. Therefore, there is no significant increase in flood risk due to the culvert structure.

2.3 Drayton Bassett viaduct

2.3.1 This crossing consists of a viaduct structure of 155m width which will cross two ordinary watercourses SWC-CFA21-002 and SWC-CFA21-003 (Volume 5: Map WR-01-035, G5) as shown in Figure 2. The watercourses flow from west of the crossing and combine into one watercourse and continue east within the model extents as shown in Figure 2.

[7] Length of reach upstream of the scheme along which flood levels during the 1 in 100 (1%) annual probability with an allowance for climate change event are greater than 10mm.

Figure 2: Crossing location plan and flood extents for Drayton Bassett viaduct



Hydrology

2.3.2 The river inflow hydrology was defined using the ReFH method only. The peak flow from the hydrology calculation was used as a constant inflow into the model. This was to ensure that the defined peak flow across the route was maintained. The nature of the floodplain at this point indicates that flow conveyance is the predominant factor rather than storage, therefore this simplification is reasonable. The details of the hydrological assessment are provided in the FEH proformas within section 3 of this report. Table 3 provides a summary of the peak flows determined from the hydrological calculations.

Table 3: Hydrology results: Model inflows

Watercourse identifier	Environment Agency Flood Zone	1 in 20 (5%) flow	1 in 100 (1%) climate change flow	1 in 1000 (0.1%) flow	Modelled structure
SWC-CFA21-002	3	1.35m^3/s	2.35m^3/s	3.66m^3/s	Viaduct
SWC-CFA21-003	3	1.87m^3/s	3.27m^3/s	5.08m^3/s	Viaduct

Hydraulics

2.3.3 The TUFLOW model was built on a 5m cell resolution. The two dimensional domain covered the floodplain of these watercourses, the extents of which were defined by the available LiDAR data. The inflows to the watercourses were applied upstream

using a boundary condition polyline layer, linking it to a constant flow time series within a boundary condition database. The downstream boundary was a HQ polyline layer based on the water surface gradient of 0.01 for the floodplain at that location; which was 0.01 in this case. The resulting baseline models were run at a two second timestep over the duration of five hours.

2.3.4 The viaduct structure was modelled by adding FC shape layers which represented the piers. The suggested pier dimension was 2m, however, for simplicity a percentage blockage of 50% and a form loss coefficient was added to the cells in the location of the piers. The embankments on either side of the viaduct were modelled as Z-polygon layers. The soffit levels were not added into the model. This was because the 1 in 1000 (0.1%) annual probability modelled peak flood levels, along with sufficient clearance, would form the basis of designing the soffit heights.

2.3.5 Further sensitivity was undertaken on the viaduct piers by increasing the percentage blockage to 100% which would have accounted for temporary works. There was no change in modelled peak levels as a result.

2.3.6 Hydraulic constraints:

- the OS mapping and aerial photographs indicate that there are no major hydraulic constraints on the watercourses such as culvert or bridge crossings; and
- Watercourses SWC-CFA21-002 and SWC-CFA21-003 combine into a single watercourse with a combined floodplain at the route crossing. Hence, this assessment of river flood risk includes both the watercourses.

2.3.7 The floodplain width at the crossing is 154m for the 1 in 100 (1%) annual probability with an allowance for climate change event. The cross section of the watercourse with baseline flood levels upstream of the crossing is shown in Figure 3, below. The impact of the scheme on modelled peak levels is summarised in Table 4. The baseline peak velocity contours and scheme impact on velocities are shown in Figure 4, below.

Table 4: Modelled peak levels for Drayton Bassett viaduct

Flood event	**Peak flood level**		**Change in flood level**
	Baseline	**Scheme**	
1 in 20 (5%)	85.761mAOD	85.761mAOD	1 in 20 (5%)
1 in 100 (1%) climate change	85.786mAOD	85.786mAOD	1 in 100 (1%) climate change
1 in 1000 (0.1%)	85.810mAOD	85.810mAOD	1 in 1000 (0.1%)

Figure 3: Cross section and flood levels at Drayton Bassett viaduct

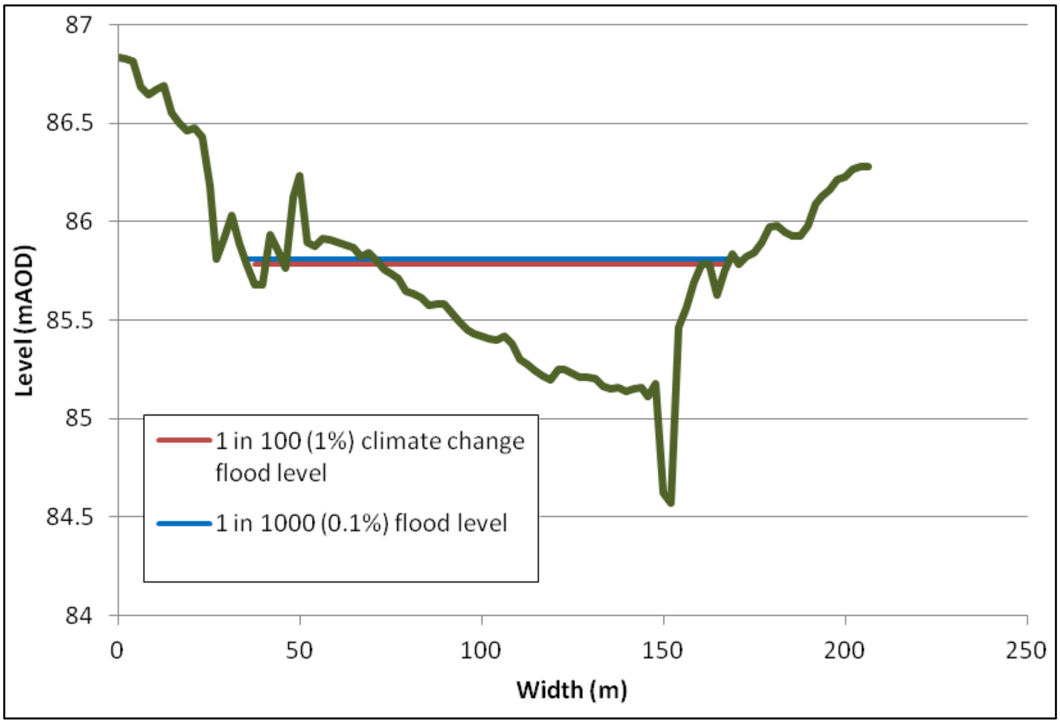
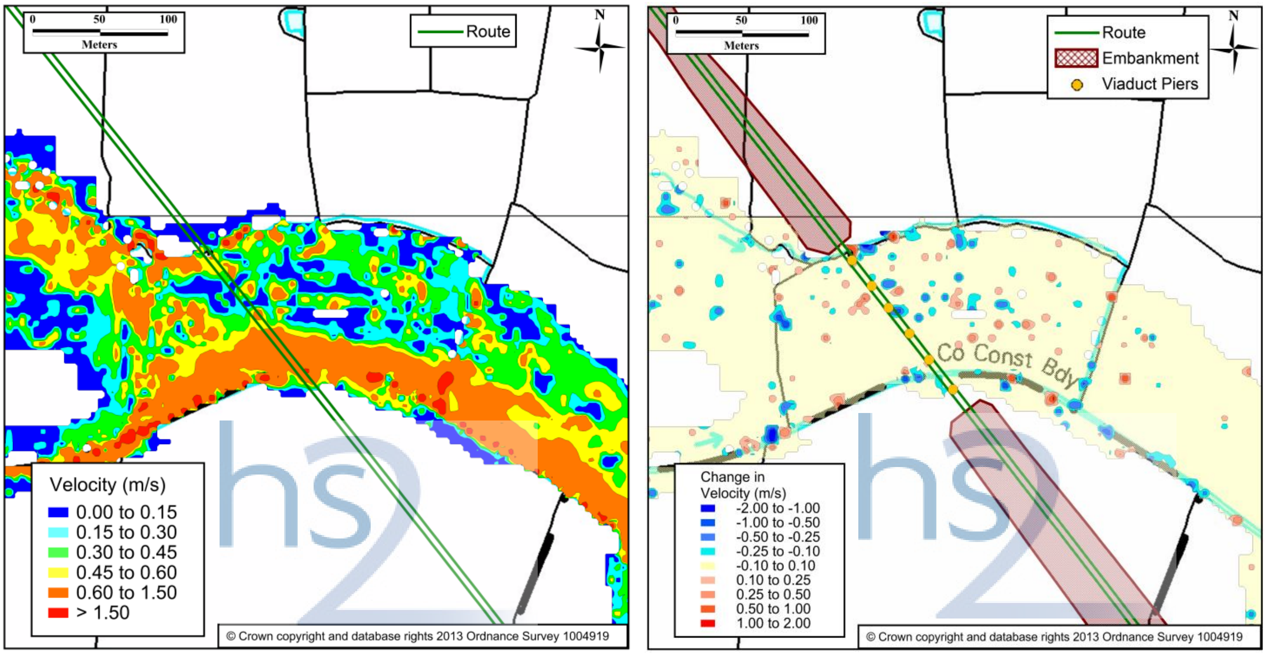


Figure 4: Modelled peak velocity contours for 1 in 100 (1%) climate change event for Drayton Bassett viaduct



Sensitivity assessment

2.3.8 Sensitivity assessment was undertaken on the inflows by adding 20% to the design inflows of the 1 in 100 (1%) annual probability with an allowance for climate change and 1 in 1000 (0.1%) annual probability events. Models were run for both the baseline and scheme scenarios.

2.3.9 For the various scenarios, peak levels increased up to a maximum of 13mm which was considered minimal. However, the soffit level will be sufficiently above the modelled peak levels with sensitivity allowance, providing the design clearance of 600mm.

2.3.10 The flood extents increase by up to 4% for the 1 in 100 (1%) annual probability with an allowance for climate change event. There are no additional receptors affected as a result.

2.3.11 Therefore, the impact of the scheme on flood risk will still be valid with these sensitivity changes.

Conclusions

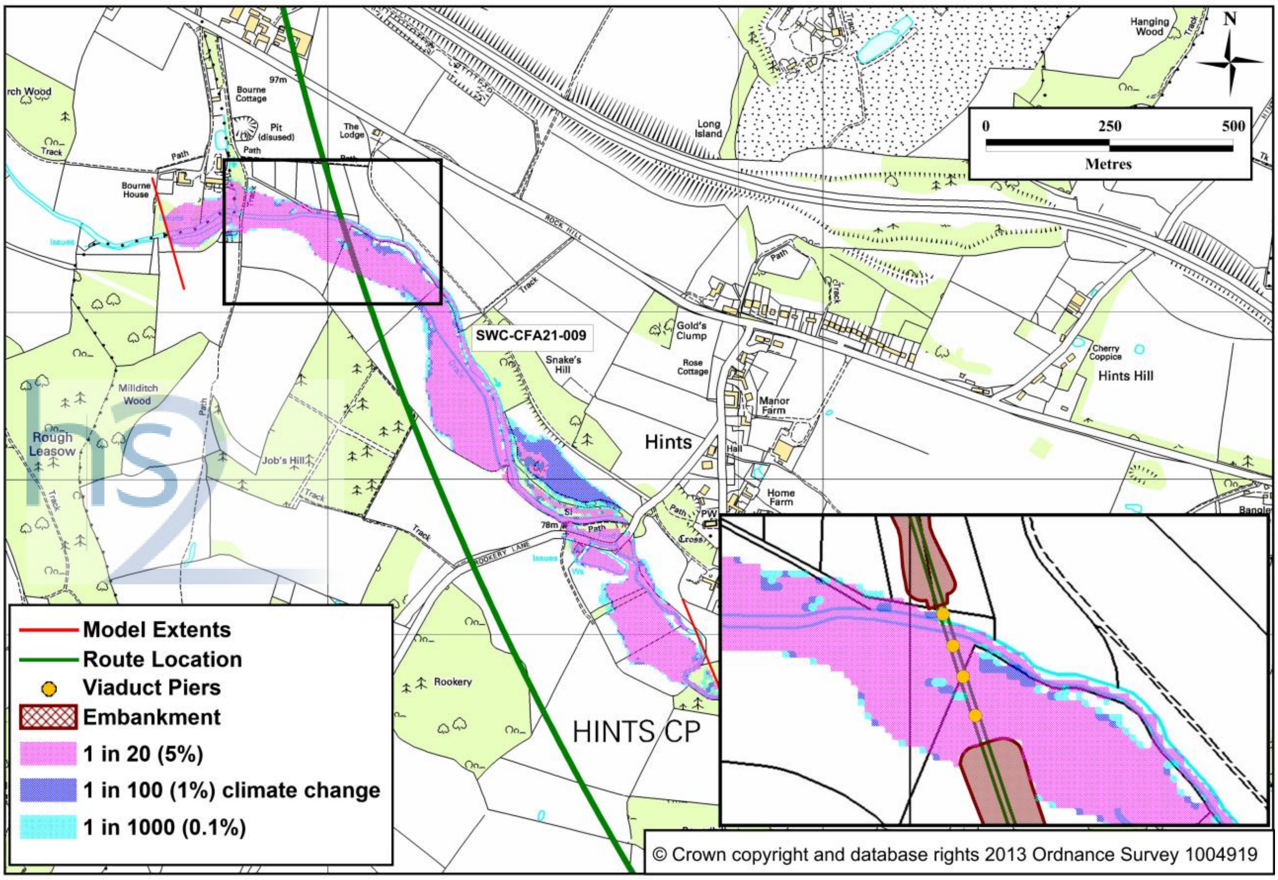
2.3.12 The proposed viaduct structure showed no increase in peak levels for the 1 in 100 (1%) annual probability event. Therefore, the viaduct will have no impact on flood risk upstream.

2.3.13 There will be no significant increases in velocities due to the viaduct structure.

2.4 Black Brook viaduct

2.4.1 This crossing consists of a viaduct structure of 105m width which will cross the ordinary watercourse Black Brook SWC-CFA21-009 (Volume 5: Map WR-01-035, B5) as shown in Figure 5. The watercourse flows from west of the crossing and continues east within the model extents as shown in Figure 5.

Figure 5: Cross section location and flood extents for Black Brook viaduct



Hydrology

2.4.2 The river inflow hydrology was defined using the ReFH method only. The peak flow from the hydrology calculation was used as a constant inflow into the model. This was to ensure that the defined peak flow across the route was maintained. The nature of the floodplain at this point indicates that flow conveyance is the predominant factor rather than storage, therefore this simplification is reasonable. The details of the hydrological assessment are provided in the FEH proformas within Section 3 of this report. Table 5 provides a summary of the peak flows determined from the hydrological calculations.

Table 5: Hydrology results: Model inflows for Black Brook

Watercourse identifier	Environment Agency Flood Zone	1 in 2 (50%) flow	1 in 20 (5%) flow	1 in 50 (2%) flow	1 in 100 (1%) climate change flow	1 in 1000 (0.1%) flow	Modelled Structure
SWC-CFA21-009	3	4.99m^3/s	7.23m^3/s	7.71m^3/s	9.61m^3/s	16.64m^3/s	Viaduct

Hydraulics

2.4.3 The TUFLOW model was built on a 5m cell resolution. The two dimensional domain covered the floodplain of the watercourse, the extents of which were defined by the available LiDAR data. The inflow to the watercourse was applied upstream using a boundary condition polyline layer, linking it to a steady state flow time series within a boundary condition database. The downstream boundary was a HQ polyline layer based on the water surface gradient of the floodplain at that location; which was 0.002 in this case. The resulting baseline model was run at a two second timestep for the duration of five hours.

2.4.4 The viaduct structure was modelled by adding FC shape layers which represented the piers. The suggested pier dimension was 2m, however, for simplicity a percentage blockage of 50% and a form loss coefficient was added to the cells in the location of the piers. The embankments on either side of the viaduct were modelled as Z-polygon layers. The soffit levels were not added into the model. This was because the 1 in 1000 (0.1%) annual probability modelled peak flood levels, along with sufficient clearance, would form the basis of designing the soffit heights.

2.4.5 These models were run for the 1 in 2 (50%) annual probability, 1 in 20 (5%) annual probability, 1 in 50 (2%) annual probability, 1 in 100 (1%) annual probability with an allowance for climate change and the 1 in 1000 (0.1%) annual probability events. More frequent design events than the 1 in 20 (5%) annual probability were run for this watercourse crossing as there were 'More Vulnerable' receptors affected by flooding.

2.4.6 Further sensitivity was undertaken on the viaduct piers by increasing the percentage blockage to 100% which would have accounted for temporary works. There was no change in modelled peak levels as a result.

2.4.7 Hydraulic constraints:

- the extent of the two dimensional model is limited to the spatial extent of the available LiDAR data. There are no road bridges upstream of the crossing within the model extent which would have had an impact on flood risk. The

Bookery Lane Road Bridge is 800m downstream of the crossing and was assumed to have negligible impact on flood risk at the site due to the slope of the topography; and

- there are no lakes and ponds within the floodplain of the watercourse which could have potentially influenced flood risk at the crossing.

2.4.8 The floodplain width at the crossing is 154m for the 1 in 100 (1%) annual probability with an allowance for climate change event. The cross section of the watercourse with baseline flood levels upstream of the crossing is shown in Figure 6.The impact of the scheme on modelled peak levels is summarised in Table 6. The baseline peak velocity contours and scheme impact on velocities are shown in Figure 7.

Table 6: Modelled peak levels for Black Brook

Flood event	Peak flood level		Change in flood level
	Baseline	Scheme	
1 in 2 (50%)	79.713mAOD	79.759mAOD	1 in 2 (50%)
1 in 20 (5%)	79.764mAOD	79.815mAOD	1 in 20 (5%)
1 in 50 (2%)	79.773mAOD	79.825mAOD	1 in 50 (2%)
1 in 100 (1%) climate change	79.816mAOD	79.871mAOD	1 in 100 (1%) climate change
1 in 1000 (0.1%)	79.902mAOD	79.976mAOD	1 in 1000 (0.1%)

Figure 6: Cross section and flood levels at Black Brook viaduct

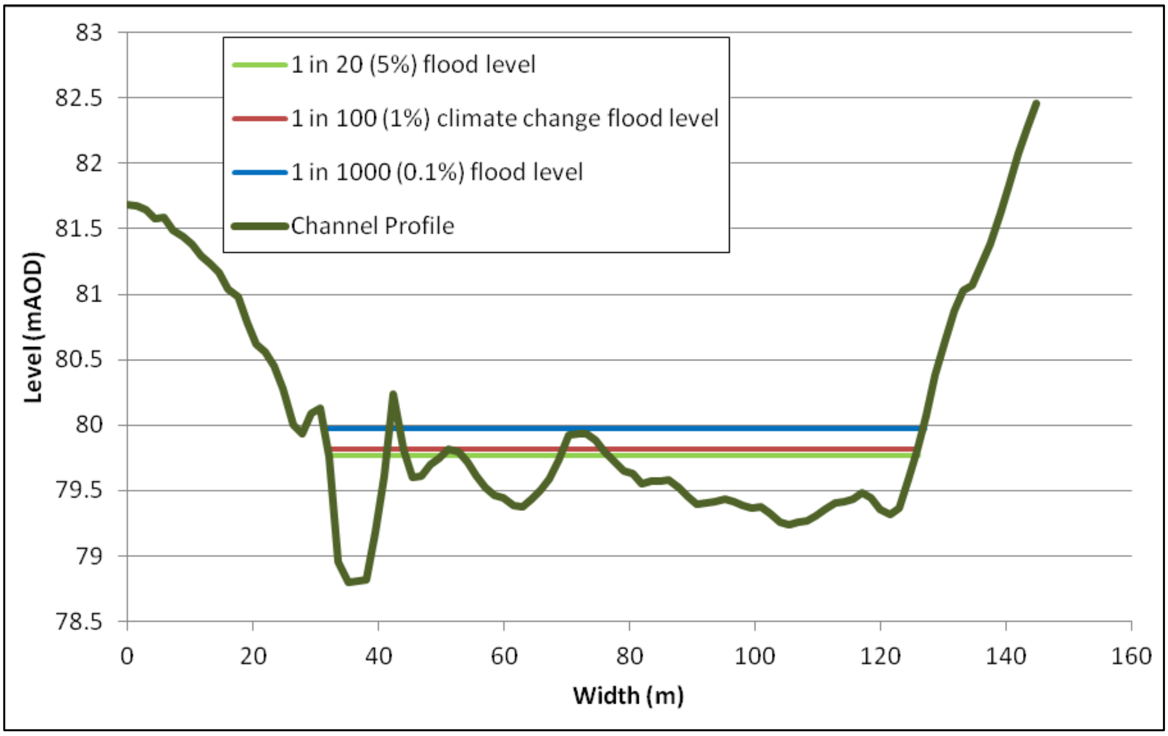
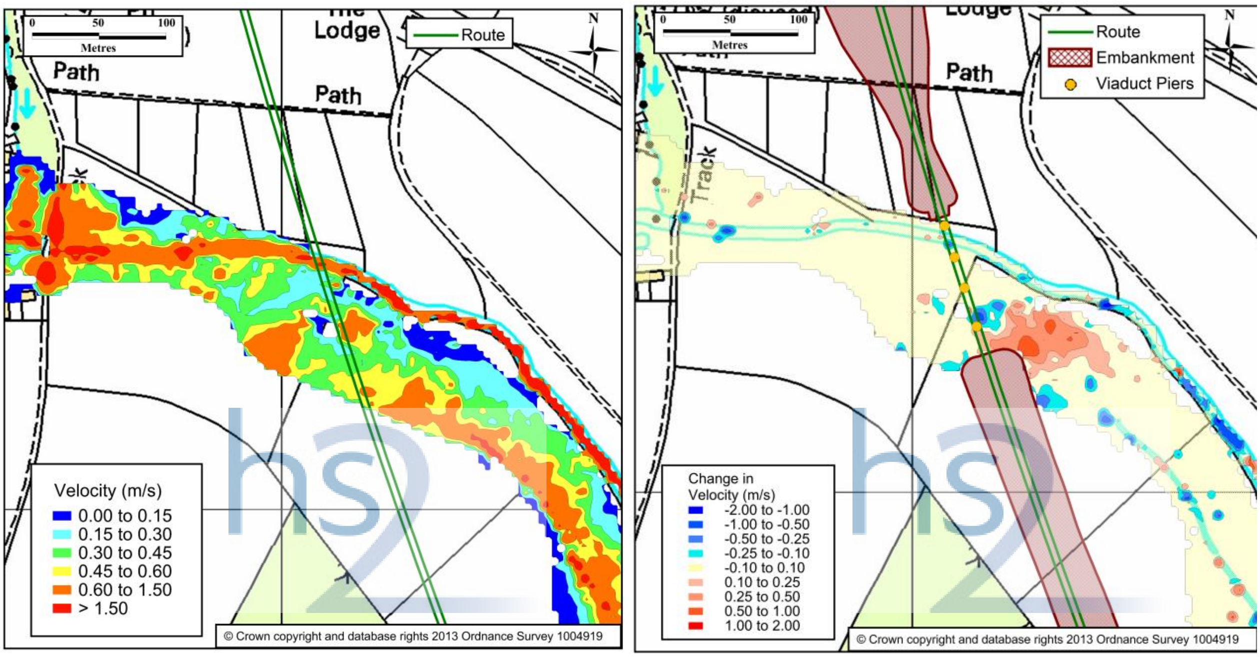


Figure 7: Modelled 1 in 100 (1%) climate change peak velocity contours at Black Brook viaduct



Sensitivity assessment

2.4.9 Sensitivity assessment was undertaken on inflows by adding 20% to the design inflows of the 1 in 100 (1%) annual probability with an allowance for climate change and the 1 in 1000 (0.1%) annual probability events for both the baseline and scheme scenarios.

2.4.10 For the various scenarios, peak levels increased up to a maximum of 54mm. However, the soffit level will be sufficiently above the modelled peak levels with sensitivity allowance, providing the design clearance of 600mm.

2.4.11 The flood extents increased by up to 6% which was not significant and would not have affected any additional properties.

Conclusions

2.4.12 For the proposed viaduct structure, the increase in peak level for the 1 in 100 (1%) annual probability with an allowance for climate change event greater than 10mm was limited to 83m upstream of the structure. There was increase of peak levels of 55mm about 30m upstream of the crossing.

2.4.13 A replacement flood storage area has been identified which mitigates this increase of peak level and has been confirmed with further modelling. The scheme with mitigation showed a 25mm increase in 1 in 100 (1%) annual probability with an allowance for climate change event. Therefore, the impact has changed from a moderate impact to a minor impact.

2.4.14 There was localised increase in peak velocities of 0.7m/s at the south embankment and with minimal changes elsewhere.

3 FEH proformas

3.1 Overview

3.1.1 This section provides the FEH proformas for the hydrological calculations of the watercourses for which there were no existing hydrology available.

3.1.2 The FEH proformas are based on the Environment Agency supporting document to the flood estimation guidelines[8].

3.1.3 The FEH proformas provided here cover the watercourses at Gallows Brook culvert, Drayton Bassett viaduct, Hints culvert, Roundhill Wood culvert and Black Brook viaduct. The Drayton Bassett viaduct requires two inflows as there are two watercourses (SWC-CFA21-002 and SWC-CFA21-003) which drain to this location. The catchment to the Black Brook viaduct is a highly permeable. The first proforma presented in Section 3.2 of this report details the calculations at Gallows Brook culvert, Drayton Bassett viaduct, Hints culvert and Roundhill Wood culvert. The proforma in Section 2.4.14 of this report presents the calculations at the Black Brook viaduct.

3.1.4 The hydrological assessment for the watercourse SWC-CFA21-009 at the location of Roundhill Wood Culvert has been provided here, despite no hydraulic modelling being undertaken for this watercourse, as these flows were required to assess the culvert capacity to convey flows through the route.

3.2 Gallows Brook culvert, Drayton Bassett viaduct, Hints culvert and Roundhill Wood culvert

Method statement

Overview of requirements for flood estimates

Item	Comments
Give an overview which includes: Purpose of study Approx. no. of flood estimates required Peak flows or hydrographs? Range of return periods and locations Approx. time available	This proforma outlines the hydrological calculations carried out for the assessment of flood risk. As part of the Proposed Scheme, a number of watercourses will require culvert structures under the rail line and hence it must be ensured that the culvert would be of sufficient capacity. Where a culvert would not have sufficient capacity, a larger culvert, bridge structure or viaduct would be required. It is vital at this stage that the proposed structures are not under designed and hence conservative flows are necessary in line with current requirements of the Proposed Scheme. At a later stage, if a more in-depth assessment determines lower flow, and hence smaller structures would have sufficient capacity, this is acceptable. Flows are required at all 29 watercourse crossings within the Tame Catchment of the study area. This assessment outlines the derivation of flows at the five locations within this study area. For these locations flows have been derived for the 1 in 20 (5%), 1 in 100 (1%), 1 in 100 (1%) with an allowance for climate change and the 1 in 1000 (0.1%) annual probability events. At this stage only peak flows are required.

[8] Environment Agency, (2012). *Flood estimation guidelines, operational instruction 197_08*.

Overview of catchment

Item	Comments
Brief description of catchment, or reference to section in accompanying report	The four crossings have separate catchments which are rural in nature. The catchments also range in size from 0.55km² to 2.97km².

Source of flood peak data

Was the HiFlows UK dataset used? If so, which version? If not, why not? Record any changes made	No. Only method implemented at this stage is ReFH and hence HiFlows data is not utilised.

Gauging stations (flow or level)

3.2.1 Gauging stations at the sites of flood estimates or nearby at potential donor sites.

Water-course	Station name	Gauging authority number	National River Flow Archive number (used in FEH)	Grid reference	Catchment area (km²)	Type (rated / ultrasonic / level...)	Start and end of flow record
Not applicable							

Data available at each flow gauging station

Station name	Start and end of data in HiFlows-UK	Update for this study?	Suitable for QMED?	Suitable for pooling?	Data quality check needed?	Other comments on station and flow data quality – e.g. information from HiFlows-UK, trends in flood peaks, outliers.
Not applicable						
Give link/reference to any further data quality checks carried out						

Rating equations

Station name	Type of rating e.g. theoretical, empirical; degree of extrapolation	Rating review needed?	Reasons – e.g. availability of recent flow gaugings, amount of scatter in the rating.
Not applicable			
Give link/reference to any rating reviews carried out			

Other data available and how it has been obtained

Type of data	Data relevant to this study?	Data available?	Source of data and licence reference if from Environment Agency	Date obtained	Details
Check flow gaugings (if planned to review ratings)	No				
Historic flood data – give link to historic review if carried out.	No				
Flow data for events	No				
Rainfall data for events	No				
Potential evaporation data	No				
Results from previous studies	Yes				
Other data or information (e.g. groundwater, tides)	No				

Initial choice of approach

Is FEH appropriate? (it may not be for very small, heavily urbanised or complex catchments) If not, describe other methods to be used.	ReFH has been utilised for this assessment where appropriate, as a quick method for determining flows. At this stage the assessment is specifically aimed at determining at which locations the proposed culvert or bridge would have sufficient capacity for flood flows, and hence whether the Proposed Scheme design requires mitigation. This assessment does not include heavily urbanised catchments or complex ones. In cases where catchments are not represented on the FEH CD-ROM such as at Roundhill Wood culvert, a scaling method based on area has been used.

Outline the conceptual model, addressing questions such as: Where are the main sites of interest? What is likely to cause flooding at those locations? (peak flows, flood volumes, combinations of peaks, groundwater, snowmelt, tides…) Might those locations flood from runoff generated on part of the catchment only, e.g. downstream of a reservoir? Is there a need to consider temporary debris dams that could collapse?	The main sites of interest are at the crossing locations and hence are the points at which flow has been derived. Each point at which flow has been derived has been named in accordance with the associated watercourse identifier. At this stage it is considered that peak flows are likely to be the main cause of flooding, following development, due to the potentially constricting culvert or bridge.
Any unusual catchment features to take into account? e.g. highly permeable – avoid ReFH if BFIHOST>0.65, consider permeable catchment adjustment for statistical method if SPRHOST<20% highly urbanised – avoid standard ReFH if URBEXT1990>0.125; consider FEH Statistical or other alternatives; consider method that can account for differing sewer and topographic catchments pumped watercourse – consider lowland catchment version of rainfall-runoff method major reservoir influence (FARL<0.90) – consider flood routing extensive floodplain storage – consider choice of method carefully	All catchments have a FARL >0.9. No catchments are heavily urbanised or highly permeable.
Initial choice of methods and reasons Will the catchment be split into subcatchments? If so, how?	ReFH has been used as the main method for determining flows apart from Roundhill Wood culvert where a scaling method was adopted. For the purposes of this assessment it was assumed that the catchment descriptors and boundaries as output from the FEH CD-ROM are accurate and hence no manual adjustment was carried out.
Software to be used (with version numbers)	FEH CD-ROM v3.0[9] ISIS Free 3.3

Summary of subject sites

Site code (taken from watercourse identifier)	Watercourse	Site and map reference	Easting	Northing	AREA on FEH CD-ROM (km^2)	Revised AREA if altered
SWC-CFA21-001	Ordinary watercourse (Gallows Brook)	Gallows Brook culvert Map CT-06-116,G6	417820	299260	0.59	Not altered

[9] *FEH CD-ROM v3.0* © NERC (CEH). © Crown copyright. © AA. 2009. All rights reserved.

Site code (taken from watercourse identifier)	Watercourse	Site and map reference	Easting	Northing	AREA on FEH CD-ROM (km²)	Revised AREA if altered
SWC-CFA21-002	Ordinary watercourse (tributary of the River Tame)	Drayton Bassett viaduct Map CT-06-117, J6.	417600	299600	2.08	Not altered
SWC-CFA21-003	Ordinary watercourse (tributary of the River Tame)	Drayton Bassett viaduct Map CT-06-117, J6.	417490	299740	2.97	Not altered
SWC-CFA21-006	Ordinary watercourse (tributary of Bourne Brook)	Hints culvert Map CT-06-118, D6	415950	301690	0.55	Not altered
SWC-CFA21-008	Ordinary watercourse (tributary of Bourne Brook)	Roundhill Wood culvert Map CT-06-118, B6	415710	302040	Not on FEH CD-ROM	1.10
Reasons for choosing above locations		Locations the route is proposed to cross the respective watercourses.				

Important catchment descriptors at each subject site (incorporating any changes made)

Site code	FARL	PROPWET	BFIHOST	DPLBAR (km)	DPSBAR (m/km)	SAAR (mm)	SPRHOST	$URBEXT_{2000}$	FPEXT
SWC-CFA21-001	1.000	0.31	0.355	0.73	29.1	667	42.85	0.002	0.081
SWC-CFA21-002	1.000	0.31	0.389	2.04	32.2	681	39.40	0.000	0.047
SWC-CFA21-003	0.913	0.31	0.420	2.26	50.6	687	37.37	0.001	0.036
SWC-CFA21-006	1.000	0.31	0.626	0.71	78.6	689	26.83	0.000	0.005

Checking catchment descriptors

Record how catchment boundary was checked and describe any changes (refer to maps if needed)	Catchment boundaries were not checked; it was assumed that catchment boundaries as shown on the FEH CD-ROM were accurate. Where detailed assessment is required at a later stage, it is recommended that catchment boundaries are fully checked. This may result in different flows than those outlined within this proforma. Catchments not represented on the FEH CD-ROM were determined using OS and topographic mapping.
Record how other catchment descriptors (especially soils) were checked and describe any changes. Include before/after table if necessary.	This proforma outlines the hydrological assessment for the initial stage of assessment; as a result no further checking of catchment descriptors was carried out.
Source of URBEXT	$URBEXT_{1990}$
Method for updating of URBEXT	CPRE formula from FEH Volume 4[10]

[10] *Flood Estimation Handbook – Volume 4: Restatement and application of the Flood Studies Report rainfall-runoff method (1999)*, Centre for Ecology & Hydrology (CEH).

Revitalised flood hydrograph (ReFH) method

Parameters for ReFH model

Site code	Method: OPT: Optimisation BR: Baseflow recession fitting CD: Catchment descriptors DT: Data transfer (give details)	Tp (hours) Time to peak	Cmax (mm) Maximum storage capacity	BL (hours) Baseflow lag	BR Baseflow recharge
SWC-CFA21-001	CD	1.79	296	27	0.804
SWC-CFA21-002	CD	3.24	322	35	0.887
SWC-CFA21-003	CD	3.03	347	37	0.964
SWC-CFA21-006	CD	1.34	507	35	1.483
Brief description of any flood event analysis carried out (further details should be given below or in a project report)		None at this stage of the assessment.			

Design events for ReFH method

Site code	Urban or rural	Season of design event (summer or winter)	Storm duration (hours)	Storm area for ARF (if not catchment area)
SWC-CFA21-001	Rural	Winter	2.9	0.978
SWC-CFA21-002	Rural	Winter	5.5	0.973
SWC-CFA21-003	Rural	Winter	5.1	0.969
SWC-CFA21-006	Rural	Winter	2.3	0.976
Are the storm durations likely to be changed in the next stage of the study, e.g. by optimisation within a hydraulic model?			Storm durations will not be altered as part of the next stage hydraulic modelling.	

Flood estimates from the ReFH method

Site code	Flood peak (m^3/s) for the following flood events				Scaling factor
	1 in 20 (5%)	1 in 100 (1%)	1 in 100 (1%) climate change*	1 in 1000 (0.1%)	1% flow per km^2
SWC-CFA21-001	0.54	0.81	0.97	1.54	1.37
SWC-CFA21-002	1.35	1.96	2.35	3.66	0.94
SWC-CFA21-003	1.87	2.72	3.27	5.08	0.92
SWC-CFA21-006	0.29	0.45	0.54	0.89	0.81

*The 1 in 100 (1%) annual probability event flow with an allowance for climate change is the 1 in 100 (1%) annual probability event flow factored by 1.2.

Scaling for catchment not represented on the FEH CD-ROM

Site code	Manual Catchment Area (km^2)	Scaled Flows 1 in 100 (1%) climate change	Scaled Flows 1 in 1000 (0.1%)
SWC-CFA21-008	1.10	1.98	3.80
The flows in this table were estimated using the largest scaling factor as determined in the earlier table of ReFH flood estimates and a 10% allowance for data error. This ensures that the values flows estimated for these catchments not represented on the FEH CD-ROM are conservative.			

Discussion and summary of results

Comparison of results from different methods

3.2.2 This table compares peak flows from various methods with those from the FEH Statistical method at example sites for two key return periods. Blank cells indicate that results for a particular site were not calculated using that method.

Site code	Ratio of peak flow to FEH Statistical peak					
	1 in 2 (50%)			1 in 100 (1%)		
	ReFH	Other method	Other method	ReFH	Other method	Other method
	Not applicable			Not applicable		

Only the ReFH method was carried out as part of this initial assessment phase.

Final choice method

Choice of method and reasons – include reference to type of study, nature of catchment and type of data available.	The ReFH method was carried out for all the catchments as represented on the FEH CD-ROM. Flows for those not represented on the FEH CD-ROM were determined through a scaling factor based on the estimated flows for the other (FEH CD-ROM represented) catchments. The scaling took the most conservative value and also included an allowance for data error.

Assumptions, limitations and uncertainty

List the main assumptions made (specific to this study)	The FEH accurately represented the catchment boundaries and catchment descriptors. The scaling factor is indeed conservative and hence produces conservative flow estimates for all catchments not represented on the FEH CD-ROM.
Discuss any particular limitations, e.g. applying methods outside the range of catchment types or return periods for which they were developed	None
Give what information you can on uncertainty in the results	There is some uncertainty with the results based on the assumptions listed above, however it is considered that the results are conservative and hence would be overestimating, rather than under estimating.
Comment on the suitability of the results for future studies, e.g. at nearby locations or for different purposes.	The results should be used for comparative purposes only and for this initial assessment only. The results could be used as a starting point for detailed assessment; however, a more detailed hydrological assessment would be required.
Give any other comments on the study, for example suggestions for additional work.	When the assessment moves to the detailed design phase it is recommended that the catchment boundaries are checked against LiDAR, OS mapping and other such sources. It is also recommended that the FEH Statistical method is carried out, particularly for high risk crossings or in locations where the ReFH method is not the most ideal. If possible the FEH Statistical method should be carried out for all catchments for comparative purposes and to provide a greater level of confidence with the results.

Checks

Are the results consistent, for example at confluences?	Not applicable – separate catchments assessed.
What do the results imply regarding the return periods of floods during the period of record?	Not applicable
What is the 100-year growth factor? Is this realistic? (The guidance suggests a typical range of 2.1 to 4.0)	Not determined.
If 1000-year flows have been derived, what is the range of ratios for 1000-year flow over 100-year flow?	Varying between 1.87 and 2.3.
What range of specific runoffs (l/s/ha) do the results equate to? Are there any inconsistencies?	Different catchments so not comparable.
How do the results compare with those of other studies? Explain any differences and conclude which results should be preferred.	None.
Are the results compatible with the longer-term flood history?	None.
Describe any other checks on the results	None.

Final results

Site code	Flood peak (m^3/s) for the following flood events			
	1 in 20 (5%)	**1 in 100 (1%)**	**1 in 100 (1%) climate change**	**1 in 1000 (0.1%)**
SWC-CFA21-001	0.54	0.81	0.97	1.54
SWC-CFA21-002	1.35	1.96	2.35	3.66
SWC-CFA21-003	1.87	2.72	3.27	5.08
SWC-CFA21-006	0.29	0.45	0.54	0.89
SWC-CFA21-008	-	-	1.98	3.80
If flood hydrographs are needed for the next stage of the study, where are they provided? (e.g. give filename of spreadsheet, name of ISIS model, or reference to table below)				Hydrographs not required at this stage.

3.3 Black Brook viaduct

Method statement

Overview of requirements for flood estimates

Item	Comments
Give an overview which includes: Purpose of study Approx. no. of flood estimates required Peak flows or hydrographs? Range of return periods and locations Approx. time available	This proforma outlines the hydrological calculations carried out for the assessment of flood risk. The assessment phase of river flood risk included an estimation of flow within watercourses crossed by the route. The initial assessment produced quick flow estimates through the use of the ReFH model. However, as part of the assessment it was determined that the catchment at the Black Brook viaduct is highly permeable in nature and hence the flood estimation guidelines[4] state that ReFH is not appropriate for this catchment. This calculation record outlines the estimation of flow for the watercourse at the Black Brook viaduct using the recommended approach. The flows are required to provide an indication of size requirements for the route crossings to prevent increases in flood risk as a result of the scheme. The flow will also be used to determine the 1 in 1000 (0.1%) annual probability flood level to ensure that the track is not at an unacceptable level of risk. At this stage it is necessary to follow a conservative approach, because it is vital that the culverts/bridges are not under-designed. It is acceptable at this stage that structures are over-designed and reduced (if necessary) during the detailed design phase. Flows are required for the 1 in 2 (50%), 1 in 5 (20%), 1 in 20 (5%), 1 in 100 (1%), 1 in 100 (1%) with an allowance for climate change and 1 in 1000 (0.1%) annual probability events. These flows are required at the one crossing location. At this stage only peak flows (no hydrographs) are required.

Overview of catchment

Item	Comments
Brief description of catchment, or reference to section in accompanying report	The catchment is defined by FEH catchment descriptors as being highly permeable in nature. The catchment is named in accordance with the crossing structures which is the Black Brook viaduct. The catchment is defined as moderately urbanised. The catchment for the Black Brook viaduct is primarily underlain with mudstone, siltstone and sandstones in the upstream reaches and sandstones in the downstream reaches of the catchment.

Source of flood peak data

Item	Comments
Was the HiFlows UK dataset used? If so, which version? If not, why not? Record any changes made	Yes – Version 3.1.2, December 2011

Gauging stations (flow or level)

3.3.1 Gauging stations at the sites of flood estimates or nearby at potential donor sites.

Water-course	Station name	Gauging authority number	NRFA number (used in FEH)	Grid reference	Catchment area (km²)	Type (rated/ ultrasonic/ level…)	Start and end of flow record
Not applicable							

Data available at each flow gauging station

Station name	Start and end of data in HiFlows-UK	Update for this study?	Suitable for QMED?	Suitable for pooling?	Data quality check needed?	Other comments on station and flow data quality – e.g. information from HiFlows-UK, trends in flood peaks, outliers
Not applicable						
Give link/reference to any further data quality checks carried out						

Rating equations

Station name	Type of rating – e.g. theoretical, empirical; degree of extrapolation	Rating review needed?	Reasons – e.g. availability of recent flow gaugings, amount of scatter in the rating
Not applicable			
Give link/reference to any rating reviews carried out			

Other data available and how it has been obtained

Type of data	Data relevant to this study?	Data available?	Source of data and licence reference if from EA	Date obtained	Details
Check flow gaugings (if planned to review ratings)	No				
Historic flood data – give link to historic review if carried out.	No				
Flow data for events	No				
Rainfall data for events	No				
Potential evaporation data	No				
Results from previous studies	Yes				Quick estimates taken from the initial assessment phase for the Proposed Scheme. ReFH was utilised and was not considered ideal for permeable catchments.
Other data or information (e.g. groundwater, tides)	No				

Initial choice of approach

Is FEH appropriate? (it may not be for very small, heavily urbanised or complex catchments) If not, describe other methods to be used.	FEH is appropriate for this catchment. The catchment area is 85.87 km^2 and hence within the appropriate range for the application of FEH methods. The catchment is considered to be moderately urbanised and have $URBEXT_{2000}$ value of 0.119. The catchment is not considered complex.
Outline the conceptual model, addressing questions such as: **Where are the main sites of interest?** **What is likely to cause flooding at those locations? (peak flows, flood volumes, combinations of peaks, groundwater, snowmelt, tides…)** **Might those locations flood from runoff generated on part of the catchment only, e.g. downstream of a reservoir?** **Is there a need to consider temporary debris dams that could collapse?**	The site of interest is located at the proposed watercourse crossing which is required as part of the route. As a result of the scheme, flooding at the sites of interest is likely to be caused by peak flow rather than flood volumes. There are no reservoirs or temporary dam collapses that need to be considered at the sites of interest.
Any unusual catchment features to take into account? **e.g. highly permeable – avoid ReFH if BFIHOST>0.65, consider permeable catchment adjustment for statistical method if SPRHOST<20%** **highly urbanised – avoid standard ReFH if URBEXT1990>0.125; consider FEH Statistical or other alternatives; consider method that can account for differing sewer and topographic catchments** **pumped watercourse – consider lowland catchment version of rainfall-runoff method** **major reservoir influence (FARL<0.90) – consider flood routing** **extensive floodplain storage – consider choice of method carefully**	The catchments is considered highly permeable, with BFIHOST>0.65. As a result ReFH is not considered an appropriate method. The catchments are moderately urbanised with URBEXT2000<0.125. The catchment is not located on a pumped watercourse. There is no major reservoir influence at the site of interest, with a FARL value of 0.959. It is not considered that the catchment has extensive floodplain storage.
Initial choice of methods and reasons **Will the catchment be split into subcatchments? If so, how?**	The FEH Statistical method has been applied to the catchment. As part of this assessment the permeability adjustment method has also been carried out due to the permeability nature of the catchment. A scaling method has been carried out to determine the 1 in 1000 (0.1%) annual probability flow, as discussed later.
Software to be used (with version numbers)	FEH CD-ROM v3.0[11] WINFAP-FEH v3[12]

[11] *FEH CD-ROM v3.0* © NERC (CEH). © Crown copyright. © AA. 2009. All rights reserved.
[12] *WINFAP-FEH v3* © Wallingford HydroSolutions Limited and NERC (CEH) 2009.

Summary of subject sites

Site code (taken from watercourse identifier)	Watercourse	Site and map reference	Easting	Northing	AREA on FEH CD-ROM (km^2)	Revised AREA if altered
SWC-CFA21-009	Main River (Black Brook)	Black Brook viaduct Map CT-06-120, B6	415000	303500	85.87	Not applicable
Reasons for choosing above locations		Location is proposed to cross the respective watercourse.				

Important catchment descriptors at each subject site (incorporating any changes made)

Site code	FARL	PROPWET	BFIHOST	DPLBAR (km)	DPSBAR (m/km)	SAAR (mm)	SPRHOST	URBEXT2000	FPEXT
SWC-CFA21-009	0.959	0.31	0.751	10.36	32.9	703	22.01	0.1185	0.09

Checking catchment descriptors

Record how catchment boundary was checked and describe any changes (refer to maps if needed)	The catchment boundary was checked against OS mapping and appeared to be reasonable. One area of uncertainty was in the northern/upstream area of the catchment, around Chasewater. However, redefining the catchment in this area was likely to result in a change in catchment area of less than a 2%. In addition, there was uncertainty in the extent of catchment boundaries in the developed areas. Without a significant assessment into drainage paths and the surface water sewer network it would not be possible to alter the catchment boundaries in these areas. Therefore it has been deemed appropriate to retain the FEH CD-ROM catchment for this assessment. This approach is consistent with flow estimations undertaken for all other route crossings as part of the overall scheme assessment.
Record how other catchment descriptors (especially soils) were checked and describe any changes. Include before/after table if necessary.	The catchment was checked against geology mapping, and no changes were considered necessary.
Source of URBEXT	$URBEXT_{2000}$
Method for updating of URBEXT	$URBEXT_{2000}$ – A new FEH catchment descriptor. R&D Technical Report FD1919/TR. Environment Agency 2006.

Statistical method

Search for donor sites for QMED (if applicable)

Comment on potential donor sites **Mention:** **Number of potential donor sites available** **Distances from subject site** **Similarity in terms of AREA, BFIHOST, FARL and other catchment descriptors** **Quality of flood peak data** **Include a map if necessary. Note that donor catchments should usually be rural.**	Donor sites were sought through three approaches. To identify donors in close proximity to the subject sites, the FEH CD-ROM and the Hydrometric Register (CEH, 2008)[13] were used. This approach identified seven potential donors, although on inspection of the HiFlows data set, three were classed as unsuitable for pooling or QMED. In addition four donors were identified as the top four in a pooling group using the 'OK for pooling' HiFlows data set. A further four were identified as the top four in a pooling group using the 'OK for QMED' HiFlows data set. These approaches identified a total of 12 possible donors for the catchment. It was not possible to identify any donors within 10km of the subject sites (between centroids). For this catchment there are between four and five donors which are within 50km of the site and an additional two or three within 100km. The identified potential donors vary in similarity to the subject sites. Where possible the donor most similar to the subject site has been selected. Further detail is included in the next section ('Donor sites chosen and QMED adjustment factors'). The majority of the potential donors have fairly long records of gauged data, in excess of 30 years.

Donor sites chosen and QMED adjustment factors

Potential Donors for SWC-CFA21-009

NRFA no.	Reasons for choosing or rejecting	Method (AM or POT)	Adjustment for climatic variation?	QMED from flow data (A)	QMED from catchment descriptors (B)	Adjustment ratio (A/B)*
28095	Rejected – the catchment is too urban and too large in size in comparison to the subject catchment.	AM	Not required	157.46	102.98	1.1563
28026	Rejected – this could have been a possible donor, however 54044 is considered more similar to the subject site and hence 28026 has been rejected.	AM	Not required	52.05	36.94	1.0925
28053	Rejected – even though the catchment descriptors are as similar to the subject site as 28026, the adjustment factor is <1 and hence would not follow a conservative approach.	AM	Not required	27.74	28.81	0.9884
28002	Rejected – the FARL is too low.	AM	Not required	17.52	18.56	0.9853
39042	Rejected – the catchment is slightly further than preferred from the subject site. Although this would be an acceptable donor, 28026 is considered more suitable.	AM	Not required	3.42	2.37	1.0256

[13] Centre for Ecology and Hydrology, (2008), *UK Hydrometric Register*.

NRFA no.	Reasons for choosing or rejecting	Method (AM or POT)	Adjustment for climatic variation?	QMED from flow data (A)	QMED from catchment descriptors (B)	Adjustment ratio (A/B)*
34012	Rejected – the catchment is much more permeable that the subject catchment and the distance is too great.	AM	Not required	1.01	1.23	0.9975
53013	Rejected – this would have been an acceptable donor although it is further from the subject site than desirable and 28026 is considered more suitable.	AM	Not required	15.38	11.15	1.0106
29002	Rejected – the catchment is slightly further than preferred from the subject site. Although this would be an acceptable donor, 28026 is considered more suitable. In addition the adjustment factor is <1 and hence would not follow a conservative approach.	AM	Not required	3.25	4.09	0.9945
54044	Chosen – most similar to the subject site in comparison to the other potential donors, particularly in relation to BFIHOST.	AM	Not required	4.85	6.19	0.9588
41025	Rejected – the catchment is too far from the subject site and it is not permeable enough.	AM	Not required	30.03	24.93	1.0019
54036	Rejected – the catchment is slightly further than preferred from the subject site. Although this would be an acceptable donor, 28026 is considered more suitable.	AM	Not required	13.99	12.92	1.0086
41018	Rejected – the catchment is too far from the subject site and it is not permeable enough.	AM	Not required	19.90	17.80	1.0010
Which version of the urban adjustment was used for QMED at donor sites, and why? Note: The guidelines recommend great caution in urban adjustment of QMED on catchments that are also highly permeable (BFIHOST>0.8).				Urban adjustment was carried out on the QMED using the recommended approach**.		

*Adjustment factor has been updated and include an allowance for distance from the subject site. The updated adjustment calculation is provided within the flood estimation guidelines (Environment Agency, 2012).

**Urban adjustment was required in line with the Environment Agency guidelines, page 45 because the subject site has an URBEXT2000>0.03. These guidelines also stated that the use of an urban adjustment factor based on SPRHOST (as in Winfap-FEH V3) is acceptable for catchment with BFIHOST <0.8 and hence this formula for PRUAF has been used on 177-L1.

Overview of estimation of QMED at the subject site

Site code	Method	Initial estimate of QMED (m^3/s)	Data transfer						Final estimate of QMED (m^3/s)
			NRFA numbers for donor sites used	Distance between centroids d_{ij} (km)	asg	Moderated QMED adjustment factor, $(A/B)^a$	If more than one donor		
							Weight	Weighted average adjustment factor	
SWC-CFA21-009	DT	3.90	54044	48.83	0.173	0.9588	-	-	4.99

Are the values of QMED consistent, for example at successive points along the watercourse and at confluences?	NOT APPLICABLE
Which version of the urban adjustment was used for QMED, and why?	In line with guidance, PRUAF using SPRHOST* for SWC-CFA21-009.

Notes
Methods: AM – Annual maxima; POT – Peaks over threshold; DT – Data transfer; CD – Catchment descriptors alone.
When QMED is estimated from POT data, it should also be adjusted for climatic variation. Details should be added.
When QMED is estimated from catchment descriptors, the revised 2008 equation from Science Report SC050050should be used. If the original FEH equation has been used, say so and give the reason why.
The guidelines recommend great caution in urban adjustment of QMED on catchments that are also highly permeable (BFIHOST>0.8). The adjustment method used in WINFAP-FEH v3.0.003 is likely to overestimate adjustment factors for such catchments. In this case the only reliable flood estimates are likely to be derived from local flow data.
The data transfer procedure is from Science Report SC050050. The QMED adjustment factor A/B for each donor site is given in the earlier table 'Donor sites chosen and QMED adjustment factors'. This is moderated using the power term, a, which is a function of the distance between the centroids of the subject catchment and the donor catchment. The final estimate of QMED is (A/B) a times the initial estimate from catchment descriptors.
If more than one donor has been used, use multiple rows for the site and give the weights used in the averaging. Record the weighted average adjustment factor in the penultimate column.

Derivation of pooling groups

3.3.2 The composition of the pooling groups is given in the Section 'Supporting information' later in this report.

Name of group	Site code from whose descriptors group was derived	Subject site treated as gauged? (enhanced single site analysis)	Changes made to default pooling group, with reasons Note also any sites that were investigated but retained in the group	Weighted average L-moments, L-CV and L-skew, (before urban adjustment)
SWC-CFA21-009	SWC-CFA21-009	No	Two stations were added to ensure there were enough years of data following the permeability adjustment (removal of non-flood years).	L-CV = 0.248 L-skew = 0.067

Notes:
Pooling groups were derived using in WINFAP-FEH v3. The permeability adjustment procedure was carried out on the pooling group to remove the non-flood years.
The weighted average L-moments, before urban adjustment, can be found at the bottom of the Pooling-group details window in WINFAP-FEH.

Derivation of flood growth curves at subject sites

Site code	Method (SS, P, ESS, J)	If P, ESS or J, name of pooling group	Distribution used and reason for choice	Note any urban adjustment or permeable adjustment	Parameters of distribution (location, scale and shape) after adjustments	Growth factor for 100-year return period
SWC-CFA21-009	P	177-L1	Generalised logistic as recommended in FEH	Permeable and urban adjustment	Growth curve has a shallower gradient in comparison to the non adjusted curve.	Non adjusted = 2.36 Adjusted = 1.60

Notes
Methods: SS – Single site; P – Pooled; ESS – Enhanced single site; J – Joint analysis
A pooling group (or ESS analysis) derived at one gauge can be applied to estimate growth curves at a number of ungauged sites. Each site may have a different urban adjustment, and therefore different growth curve parameters.
Urban adjustments to growth curves should use the version 3 option in WINFAP-FEH: Kjeldsen (2010)[14].

Flood estimates from the statistical method

Site code	Flood peak (m^3/s) for the following flood events					
	1 in 2 (50%)	1 in 20 (5%)	1 in 50 (2%)	1 in 100 (1%)	1 in 100 (1%) CC	1 in 1000 (0.1%)
Non-Adjusted						
SWC-CFA21-009	4.99	9.10	10.61	11.79	14.14	16.08
Permeability and Urban Adjustment						
SWC-CFA21-009	4.99	7.23	7.71	8.01	9.61	8.73

Estimation of 1 in 1000 (0.1%) annual probability flow

Scaling of 1 in 1000 (0.1%) annual probability flow

3.3.3 The FEH Statistical method is not normally the most appropriate for use in determining the 1 in 1000 (0.1%) annual probability flow. The FEH flood estimation guidelines[8] states that the ReFH method can be used to determine a ratio between the 1 in 100 (1%) and 1 in 1000 (0.1%) flow, which can then be used to factor the 1 in 100 (1%) flow estimated using the FEH Statistical method. However, it has already been noted that the ReFH method is not ideal for this catchments due to the BFIHOST values being greater than 0.65.

3.3.4 This assessment is to be used in the early stages of the design process, with the focus being not to under-design the crossing structures. When the detailed design is being completed at a later stage, it is probable that the hydrology will have to be revisited. It is therefore considered appropriate to carry out a scaling approach using flows determined through the FEH Statistical and ReFH methods at this stage.

3.3.5 It is also worthy to note that the 1 in 1000 (0.1%) flow is not to be used to size the structure. Where culverts are necessary it is only required that the structure has sufficient capacity for the 1 in 100 (1%) annual probability event with an allowance for climate change (and associated freeboards). The 1 in 1000 (0.1%) flow is to be utilised to determine flood level to ensure the track is sufficiently above this level. The proposed crossing will be a viaduct and hence the vertical alignment will be

[14] Kjeldsen T. R. (2010). *Modelling the impact of urbanisation on flood frequency relationships in the UK*. Hydrol. Res. 41. 391-405.

significantly above the 1 in 1000 (0.1%) flood level anyway. Further discussion is included within the assessment of flood risk accompanying this calculation record.

ReFH Flows

3.3.6 These flows have been taken from the initial assessment phase of flows for the scheme which only covered the design events shown below.

Site code	Flood peak (m^3/s) for the following flood events				
	1 in 20 (5%)	1 in 100 (1%)	1 in 100 (1%) climate change	1 in 1000 (0.1%)	Scaling factor
SWC-CFA21-009	8.91	13.86	16.63	28.81	2.08

FEH Statistical 1 in 1000 (0.1%) scaled flows

Site code	Flood peak (m^3/s)				
	FEH Stat 1 in 1000 (0.1%) Perm Non Adjusted*	FEH Stat 1 in 1000 (0.1%) Perm Adjusted**	Scaling factor	Updated FEH Stat 1 in 1000 (0.1%) Perm Non Adjusted*	Updated FEH Stat 1 in 1000 (0.1%) Perm Adjusted**
SWC-CFA21-009	16.08	8.73	2.08	24.51	16.64

*includes urban adjustment on QMED but not urban adjustment on growth curve.
**includes urban adjustment on QMED and growth curve.

Discussion and summary of results

Comparison of results from different methods

3.3.7 This table compares peak flows from various methods with those from the FEH Statistical method at the example site for two key return periods. Blank cells indicate that results for a particular site were not calculated using that method.

Site code	Ratio of peak flow to FEH Statistical peak					
	ReFH	Other method	Other method	ReFH	Other method	Other method
SWC-CFA21-009	-			1.73		

Final choice method

Choice of method and reasons – include reference to type of study, nature of catchment and type of data available.	The FEH Statistical method is the preferred choice due to the permeability nature of the catchments. The permeability adjustment procedure has been applied to the pooling group to remove non-flood years; however, the result of the permeability adjustment on the growth curve is a reduction in flood flows in comparison to a non-adjusted growth curve. Urban adjustment has also been applied to both the QMED and the growth curve. The guidance states that ReFH is not appropriate for these catchments and hence the flows estimated using FEH Statistical with urban and permeability adjustment have been used (as recommended within the guidelines). In line with the FEH flood estimation guidelines (Environment Agency, 2012) the scaling factor, taken from the ReFH flows, has been used to determine the 1 in 1000 (0.1%) annual probability flow.

Assumptions, limitations and uncertainty

List the main assumptions made (specific to this study)	It has been assumed that the catchment as delimited in the FEH CD-ROM is correct. The catchment appears reasonable through brief catchment boundary checking, but there is potentially some uncertainty with the urban areas contributing to flow within the catchments. This is not considered a concern at this stage, but it may be something worth assessing for the detailed design phase, particularly for the larger catchment (177-L1). Assumptions have been made in the estimation of the 1 in 1000 (0.1%) flow. It is recognised that the method undertaken does not wholly comply with the guidelines; however given the use of the 1 in 1000 (0.1%) flow within the study and that the most conservative value has been taken forward, this approach is considered acceptable. The calculation QMED has been altered based on donor catchments; it is assumed that the donor catchment are suitable.
Discuss any particular limitations, e.g. applying methods outside the range of catchment types or return periods for which they were developed	The scaling factor for the 1 in 1000 (0.1%) flow was determined from the ReFH methods. It is not normally recommended that the ReFH method is used for flow estimation in permeable catchment such as this. It should also be noted that urban, highly permeable catchments are outside the range of the vast majority of catchments from which FEH methods have been developed. The guidance (Environment Agency, 2012) states that there is very little data on the effects of urbanisation on highly permeable catchments, hence there is inherent uncertainty within the flood flows estimated as there is no measured flow data.
Give what information you can on uncertainty in the results – e.g. confidence limits for the QMED estimates using FEH 3 12.5 or the factorial standard error from Science Report SC050050 (2008).	There is potential that the flows provided within this calculation record overestimated flows; however, this is considered acceptable for the purposes of this study. Even though there is potential that the flows have been over estimated, there is also a chance that flows may have been under estimated. However given a conservative approach that has been taken in some aspects of this assessment and for the overall modelling it is considered that the overall results are unlikely to be an underestimation.
Comment on the suitability of the results for future studies, e.g. at nearby locations or for different purposes.	The flow estimates up to and including the 1 in 100 (1%) annual probability flow values would be considered acceptable for information in future studies. However new estimates would be necessary if flows were required at locations either upstream or downstream from the point of interest. It is not recommended that the results for the 1 in 1000 (0.1%) annual probability event are utilised in future studies.
Give any other comments on the study, for example suggestions for additional work.	Although not anticipated necessary, a detailed assessment of the catchment boundaries could be carried out, particularly for the urban contributions to the catchments. The FEH Rainfall-runoff method could also be applied to provide a better estimate of the 1 in 1000 (0.1%) annual probability flow if deemed necessary at a later stage.

Checks

Are the results consistent, for example at confluences?	Not applicable
What do the results imply regarding the return periods of floods during the period of record?	No flood events to compare to.
What is the 100-year growth factor? Is this realistic? (The guidance suggests a typical range of 2.1 to 4.0)	Growth factor not taking into account permeable adjustment is 2.36. Taking into account permeable adjustment the growth factor is 1.60.
If 1000-year flows have been derived, what is the range of ratios for 1000-year flow over 100-year flow?	A scaling factor of 2.08 between 1 in 100 (1%) annual probability and 1 in 1000 (0.1%) annual probability flows was applied.
What range of specific runoffs (l/s/ha) do the results equate to? Are there any inconsistencies?	Not applicable
How do the results compare with those of other studies? Explain any differences and conclude which results should be preferred.	No other studies used for comparison. ReFH flows estimated from an earlier study were utilised for this assessment.
Are the results compatible with the longer-term flood history?	No history to compare to.
Describe any other checks on the results	No other checks.

Final results

Site code	**Flood peak (m^3/s) for the following flood events**					
	1 in 2 (50%)	**1 in 20 (5%)**	**1 in 50 (2%)**	**1 in 100 (1%)**	**1 in 100 (1%) climate change**	**1 in 1000 (0.1%)**
SWC-CFA21-009	4.99	7.23	7.71	8.01	9.61	16.64
If flood hydrographs are needed for the next stage of the study, where are they provided? (e.g. give filename of spreadsheet, name of ISIS model, or reference to table below)						Hydrographs not required at this stage.

Supporting information

Default Pooling Groups for SWC-CFA21-009

Name	nYears	L-CV	l-skew	Discordancy	Distance
39042 (Leach @ Priory Mill Lechlade)	37	0.195	0.021	0.503	0.212
34012 (Burn @ Burnham Overy)	43	0.235	-0.12	1.611	0.271
53013 (Marden @ Stanley)	40	0.313	0.263	1.764	0.326
29002 (Great Eau @ Claythorpe Mill)	46	0.37	0.442	2.663	0.343
37014 (Roding @ High Ongar)	46	0.255	-0.142	2.06	0.406
43017 (West Avon @ Upavon)	39	0.24	0.084	0.096	0.412
43014 (East Avon @ Upavon)	38	0.2	0.052	0.611	0.413
52004 (Isle @ Ashford Mill)	47	0.141	0.017	2.126	0.48
53023 (Sherston Avon @ Fosseway)	33	0.211	0.089	0.4	0.501
36012 (Stour @ Kedington)	42	0.282	0.185	0.218	0.533
37003 (Ter @ Crabbs Bridge)	45	0.253	-0.018	0.358	0.546
26003 (Foston Beck @ Foston Mill)	49	0.248	-0.021	0.561	0.567
37011 (Chelmer @ Churchend)	46	0.304	0.148	0.643	0.581
39028 (Dun @ Hungerford)	41	0.215	-0.069	0.386	0.588
Total	**592**				
Weighted means		**0.248**	**0.067**		